MINIMIZING SPARE COST FOR MULTI-BRANCH SYSTEM

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Abstract: Branching Units (BUs) in multi-branch submarine cable system may have different optical architecture designs in terms of fiber routing, OADM filter configuration, optical switch, port-to-port insertion loss compensation and etc. The different internal architectures may require one spare for each individual BU, which is costly and inconvenient for transportation, storage and maintenance.
This paper describes a universal spare BU solution for multi-branch system to minimize the cost. The spares quantity is minimized via the reasonable BU design as well as the specific fiber routing selection and interconnection management during BU assembly on board. The port-to-port insertion loss of spare BU can be tuned with passive component to ensure both flexibility and high-reliability. The design principle, advantages and potential impact on system are analyzed. This universal spare solution can greatly reduce the CAPEX/OPEX of spare BUs and facilitate the system management and maintenance.

1. INTRODUCTION

Submarine cables were once deployed in simple point to point configurations between two stations. Network architectures have become more complex over time, with the addition of branching units (BU) to connect either full fiber pairs or portions of a trunk fiber pair capacity to intermediate branch stations.

The addition of BUs, on one hand, enhances the system connectivity and reduces the whole system length as well as the construction cost, but on the other hand makes the system design, especially the spare BU design, more complex. Because BUs in multi-branch submarine cable system may have different optical architectures in terms of fiber routing, Optical Adding & Dropping Multiplexer (OADM) filter configuration, optical switch, port-to-port insertion loss compensation and etc. The different internal architectures may require one spare for each individual BU, which is costly and inconvenient for transportation, storage and maintenance.

This paper describes a universal spare BU solution for multi-branch system to minimize the cost. The spares quantity is minimized via the reasonable BU design as well as the specific fiber routing selection and interconnection management during BU assembly on board. The port-to-port insertion loss of spare BU can be tuned with passive component to ensure both flexibility and high-reliability. The design principle, advantages and potential impact on system are analyzed. This universal spare solution can greatly reduce the CAPEX/OPEX of spare BUs and facilitate the system management and maintenance.

2. BU DESIGN CONSIDERATIONS

The BU design of modern submarine cable systems aims at providing required fiber routing or traffic splitting among multiple landing stations, optical power matching and insertion loss compensation between BU and adjacent undersea housings (such as repeaters, OADM units, etc.), and a fixed or reconfigurable power feeding path.

This chapter will concentrate on the BU design considerations for multi-branch system.

Fiber Routing of BU

The internal fiber routing of BU in multi-branch system depends on specific project requirements, which may be different for each BU according the actual connectivity demands. The fiber routing is also limited by the fiber quantity restriction of each BU port as well as submarine cable cabling capability. Generally, the fiber quantity of each BU port shall be no more than 48 fibers for un-repeatered system and 32 fibers for repeatered system.

Take the following figure as an example, trunk station A is connected to trunk station B, with three full fiber drop BUs connected to intermediate branch stations C, D and E, respectively. The internal fiber routing are different for each of the BU, which are summarized in table 1.

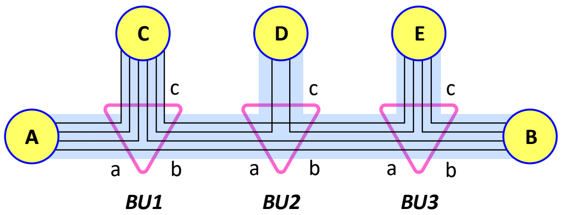


Figure 1: Fiber Routing of BU in Multi-branch System

BU ID	a-b port	a-c port	b-c port
BU1	1 FP	3 FP	3 FP
BU2	3 FP	1 FP	1 FP
BU3	2 FP	2 FP	2 FP

Table 1: Fiber Routing of BU in Multi-branch System

Optical Powering Design and Insertion Loss Compensation

The optical powering design must ensure that the upstream repeater's output power, after transmission through the cable and BU, can meet the downstream repeater's input requirement for any of the three transmission directions (a leg to b leg, b leg to c leg, a leg to c leg), and vice versa. To achieve this requirement, insertion loss fiber may be required on some of the transmission paths, to compensate for the loss where necessary.

The optical powering design requirement are further specified as below:

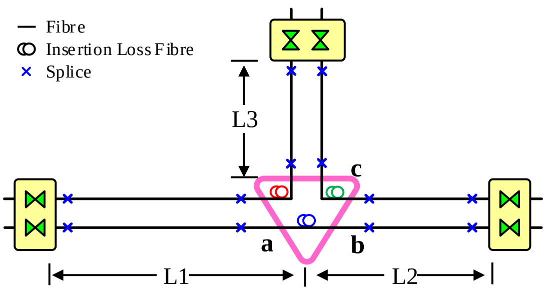


Figure 2: Optical Powering Design and Insertion Loss Compensation Diagram

- ✓ $L1 + L2 + L_{BU} + IL(a\text{-}b) + L_{inte} = G$
- ✓ $L1 + L3 + L_{BU} + IL(a\text{-}c) + L_{inte} = G$
- ✓ $L2 + L3 + L_{BU} + IL(b\text{-}c) + L_{inte} = G$

Where,

- L1, L2 and L3 are the cable loss between BU and the first adjacent repeater, for a leg, b leg and c leg side, respectively.
- L_{BU} is the inherent insertion loss of BU, including internal feed through fiber loss, splice loss, etc.
- L_{inte} is the integration loss of repeater and BU with submarine cable.
- IL(a-b), IL(b-c), IL(a-c) are the insertion loss on each fiber path, which will be added during BU manufacturing process according to project requirements.
- G is the nominal repeater gain of each span.

Considering the system transmission and BU/repeater deployment requirements, the distance from BU to adjacent repeater on a leg, b leg and c leg side may differ from each other, therefore different amount of insertion loss IL(a-b), IL(b-c), IL(a-c) will be required for each fiber path for each BU, which increase the complexity of spare BU design.

Power Switching Capability

The BU also provides electrical power routing to interconnect the power conductors of the trunk cable, branch cable and the local sea ground electrode.

The BU may provide a fixed power routing which means the power configuration cannot be changed during operation. Alternatively, electrical power switching function can be added to the BU to reconfigure the electrical connections between the power conductors in the undersea cables and the sea ground electrode. BU's power switching capability is extremely useful for network maintenance, which allows the removal of electrical power for the fault segment during cable repair, and maintain the traffic of non-fault segment as much as possible.

The power switching states of a three port power switching BU is shown in figure 3 below:

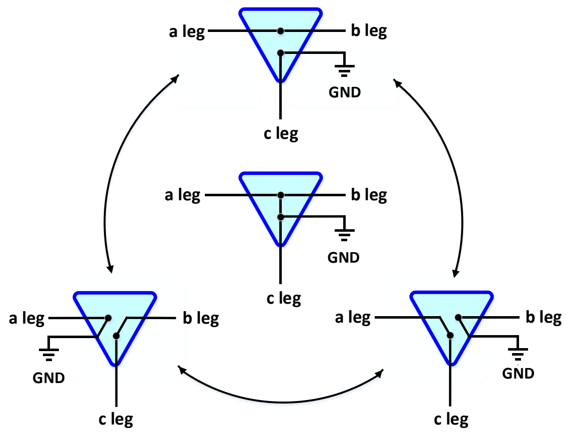


Figure 3: Power Switching Status of BU

The power switching function is realized by adding high-voltage relays between the power connector of the three BU ports and the sea ground electrode. The switching command is normally issued from terminal station equipment, with redundant command receivers (CMD) installed at each BU port to detect the command, which is shown in figure below:

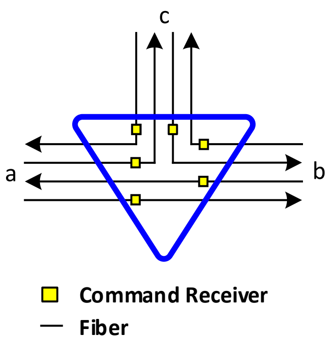


Figure 4: Typical Command Receiver Configuration

3. UNIVERSAL SPARE BU DESIGN

From the above analysis, we can see that the optical architecture may be different for each BU in multi-branch system, after an overall consideration of fiber routing, optical power design, insertion loss compensation, and power switching command receiver configuration. The different internal architectures may require one spare for each individual BU, which is costly and inconvenient for transportation, storage and maintenance. So how can we achieve a universal spare BU solution?

For easy understanding, let's take a two fiber pair repeated system with 3 BUs as an example, the network configuration is further detailed in figure 5 below.

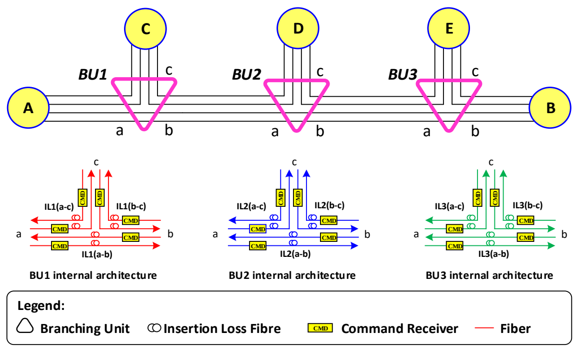


Figure 5: Optical Architecture for 2 Fiber Pair Repeated System with 3 BUs

Where, IL1(a-b) represents insertion loss fiber installed between port a and port b for BU1, which is similar for others.

3.1 Traditional Universal Spare BU Solution

The easiest way to achieve universal spare BU is to duplicate each in-line BU's internal architecture in one spare housing. In such way, the fiber quantity and internal components of spare BU is the summation of all in-line BUs. This solution has a very simple design principle but might be greatly limited by the following factors:

- BU's internal space limitation: Not like fibers, the optical and electrical components always occupy much larger space, more components in spare BU means more BU space is required. Normally for a specific BU product, the BU's internal space is already fixed, it may not be able to contain the components of all in-line BUs in one spare housing.
- Fiber quantity limitation of each BU port: Generally it shall be no more than 32 fibers for each BU port in submarine industry, considering BU feed through capacity.
- Submarine cable cabling capability: Currently the maximum fiber quantity is 32 for repeatered cable in submarine industry. It will increase the cabling difficulty if more fibers are required, currently there are few cable suppliers can provide repeatered cable with more than 32 fibers.

3.2 A Novel Universal Spare BU Solution

3.2.1 Design Principle

Considering the internal components occupy large space, the design concept of this universal spare BU solution is to configure only one set of command receivers that is suitable for all in-line BUs in the spare housing, and utilize a limited number of fiber pairs to realize as much as possible insertion loss combinations, so that it can solve the configuration variety of multi in-line BUs, and repair as much more BUs as possible.

Take figure 5 as an example, the universal spare BU can be designed as below:

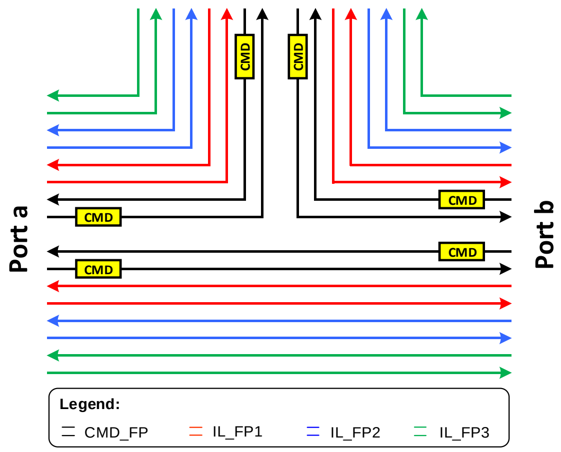


Figure 6: Optical Architecture of Spare BU

- The black fiber pair with command receivers is a common fiber pair, which will be used for all in-line BUs' repair (hereinafter referred as "**CMD_FP**").
- In order to match the port to port insertion loss of each in-line BU, dedicated fiber pairs with insertion loss equal to each in-line BU are configured (hereinafter referred as "**IL_FP**").

Take BU1 repair as an example. The red fiber pair (IL_FP1) are dedicated to repair in-line BU1, the insertion loss configuration of which are equal to each fiber path of BU1 and is specified in following table.

Red Fiber Path of Spare BU	Insertion Loss Configuration
Port a - Port b	IL1(a-c)
Port a - Port c	IL1(b-c)
Port b - Port c	IL1(a-b)

Table 2: Insertion Loss Configuration of IL_FP1 (for BU1 repair)

Where, IL1(a-c) represents insertion loss installed between port a and port c of in-line BU1.

During BU1 replacement, the operator only need to select the specific fiber routing between the IL_FP and CMD_FP according to interconnection management plan, and do the splice operation between them. All these operations will be done during spare BU's UJ assembly on board.

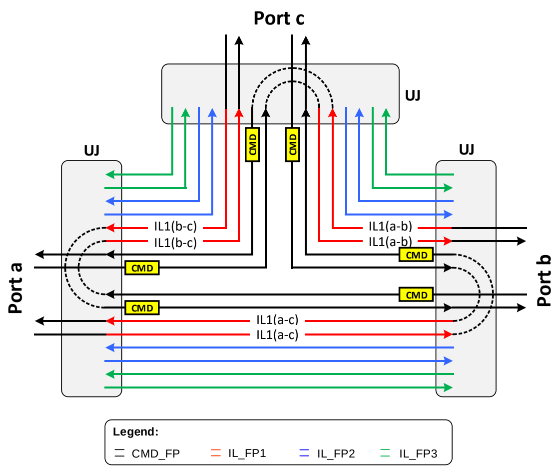
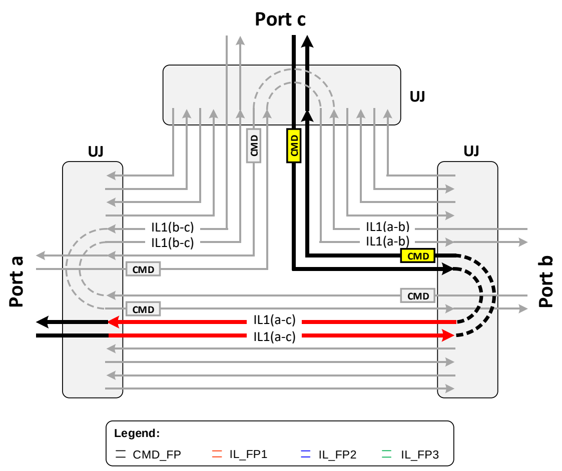


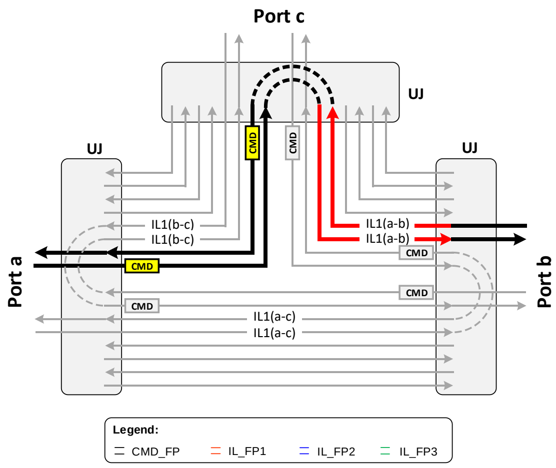
Figure 7: Spare BU Assembly on Board (for BU1 replacement)

By using this solution, the fiber path between any two ports of the spare BU need to be routed from the start port to an intermediate port and then be routed back to the end port, with half path is IL_FP and half path is CMD_FP.

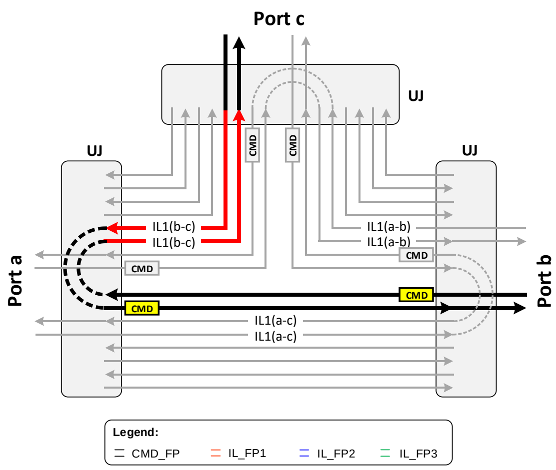
The fiber paths between two BU ports are highlighted as following:



(a) Fiber path: Port a - Port c



(b) Fiber path: Port a - Port b



(c) Fiber path: Port b - Port c

Figure 8: Highlighted Fiber Path between BU Ports (for BU1 replacement)

Red Fiber Path of Spare BU	Start -> Intermediate	Intermediate -> End
Port a - Port c	Port a -> Port b	Port b -> Port c
	IL_FP	CMD_FP
Port a - Port b	Port a -> Port c	Port c -> Port b
	CMD_FP	IL_FP
Port b - Port c	Port b -> Port a	Port a -> Port c
	CMD_FP	IL_FP

Table 3: Fiber Path Configuration (for BU1 replacement)

3.2.2 Advantages

Less Space Required

Compared with traditional spare BU solution, this solution can greatly reduce the quantity of command receivers, therefore reduce the space required for spare BU.

Expansibility

Secondary, the design can be expanded easily to allow more BUs' repair by adding additional IL_FPs between BU ports. Take figure 9 and figure 10 as an example, the blue fiber pair (IL_FP2) and green fiber pair (IL_FP3) can be used to replace BU2 and BU3 respectively, the insertion loss configuration and interconnection arrangement for blue and red fiber paths are shown in figures below.

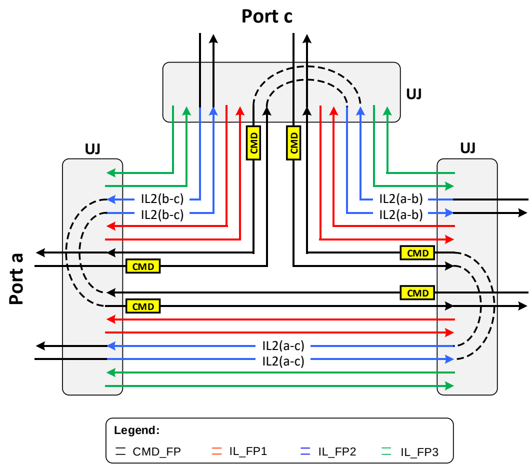


Figure 9: Spare BU Assembly on Board (for BU2 replacement)

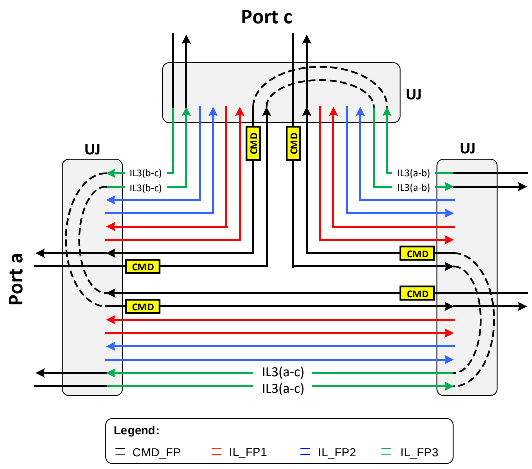
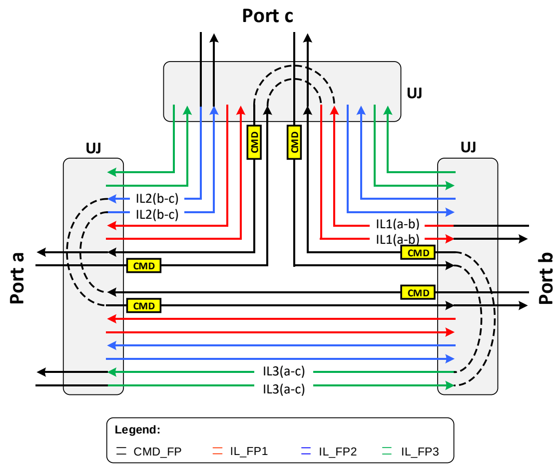


Figure 10: Spare BU Assembly on Board (for BU3 replacement)

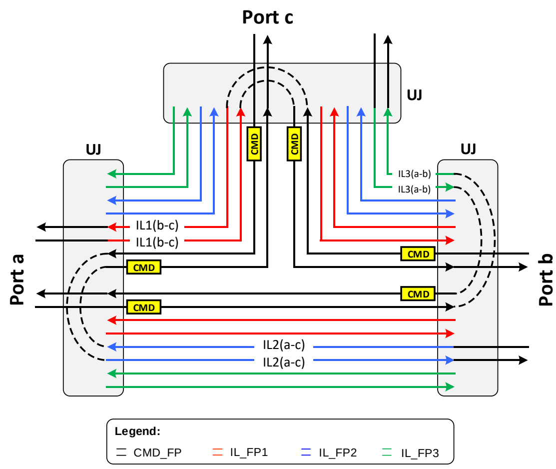
For a 16 fiber pair BU, it can support maximum 7 IL_FPs + 1 CMD_FP between each two BU ports, therefore can be used to repair maximum 7 in-line BUs. It is extremely useful for festoon repeatered system with few fiber pairs but large BU quantity.

Tunable Port to Port Insertion Loss

Besides the interconnection arrangement defined in figure 7, figure 9 and figure 10, the port to port insertion loss of spare BU can be tuned by using the IL_FP from different fiber pair groups and adjusting the connection arrangement. Which is shown in examples below:



(a) Example 1



(b) Example 2

Figure 11: Different Interconnection Arrangement to Realize Tunable Port to Port Insertion Loss

The solution can realize abundant port to port insertion loss combinations, which greatly increase the spare BU's application flexibility and might be used as common spare for other projects as well.

Symmetrical Design

Besides, the design has a symmetrical characteristic. For each fiber path, we can define the first half path as IL_FP and the last half path as CMD_FP, or vice versa. It offers design flexibility and allow the selection during spare BU design stage after an overall consideration of other fiber pairs' insertion loss requirements, and can avoid high insertion loss of different fiber pairs are concentrated between same BU ports.

Take BU1 repair as an example, the symmetrical design of spare BU is shown in figure below:

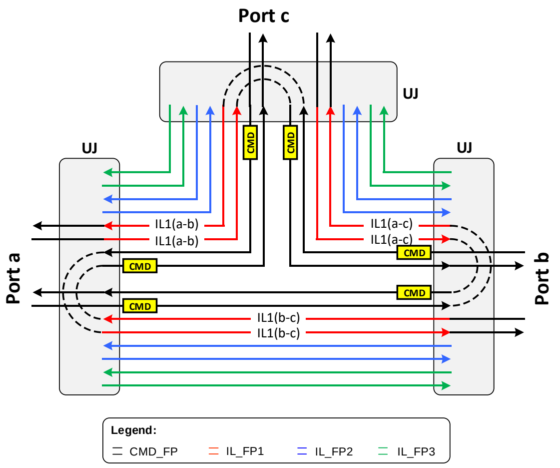


Figure 12: Symmetrical Design of Spare BU (for BU1 replacement)

Red Fiber Path of Spare BU	Start -> Intermediate	Intermediate -> End
Port a - Port c	Port a -> Port b	Port b -> Port c
	CMD_FP	IL_FP
Port a - Port b	Port a -> Port c	Port c -> Port b
	IL_FP	CMD_FP
Port b - Port c	Port b -> Port a	Port a -> Port c
	IL_FP	CMD_FP

Table 4: Symmetrical Fiber Path Configuration (for BU1 replacement)

3.2.2 Potential Impact on System

The fibre routing selection and interconnection operation between CMD_FP and IL_FP need be done during spare BU's UJ integration on board. It, to some extent, increases the complexity of on board operation and requires a skilled and experienced operator.

4. CONCLUSION

In this paper, a universal spare BU solution for multi-branch submarine cable system is presented.

Compared with the traditional solution, a dedicated CMD_FP will be configured in the spare to be used as common fiber pair for all in-line BUs' repair. Thus it can greatly decrease the command receiver quantity and reduce the space requirement of spare BU. Besides, IL_FPs are configured to match each in-line BU's insertion loss requirement. By the specific fiber routing selection and interconnection management between the CMD_FP and IL_FP, the spare BU can be used to repair multi inline BUs and therefore minimize the spare BU quantity. What's more, the port-to-port insertion loss of spare BU can be tuned by choosing IL_FPs from different fiber pair groups and adjusting the interconnection arrangement, it greatly increase the spare BU's application flexibility. This universal spare solution can reduce the CAPEX/OPEX of spare BUs and facilitate the system management and maintenance.

5. REFERENCES

[1] José Chesnoy, PhD Ex-CTO of Alcatel-Lucent, "Undersea Fiber Communication Systems" 423, 435